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VIEWS REGARDING THE VALIDITY OF RESULTS FROM SIMULATION TESTING IN COMPARISON WITH THE RESULTS FROM ACTUAL FLIGHT TEST

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16. Abstract

A comparison of the validity of results obtained by flight simulation with results obtained from actual flight tests is presented. The background for the development of the simulator is discussed. The techniques for conducting the simulation are outlined. Examples of flight simulation operations are developed. Results of the comparison indicate good correlation between simulation and flight test data.

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VIEWS REGARDING THE VALIDITY OF RESULTS FROM SIMULATION TESTING IN COMPARISON WITH THE RESULTS FROM ACTUAL FLIGHT TEST

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Abstract /30*

On hand of example of some projects carried out at the firm of Dornier, the procedure for making simulation models and the performing of software and peripheral hardware simulation is outlined as based on the problems of simulation testing. The results from simulation experiments and actual flight tests are represented by examples from aeronautical and space flights.

The following conclusions can be drawn regarding the validity of simulation experiments as based on a comparison of simulation and actual flight tests performed in the cases noted and due to different characteristic frequencies of model and actual flying equipment, "resimulation" of flight tests and simulations paralleling flight tests using simplified simulation models:

Behavior and dynamic of the model is transferable to the actual flying equipment within the range of validity of real time simulation tests.

As a rule, simulation turns out to be more favorable, especially in the case of pilot training.

Such simulation in comparison with actual flight is sufficiently accurate for the guidance of unmanned flight equipment operating out of sight of the pilot.

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* Numbers in the margin indicate pagination in the foreign text.

Introduction /31

In recent years, a series of flying apparatus developments have been carried out at the firm of Dornier that have already been partly completed. In the framework of this lecture some of these examples will be used to demonstrate in detail the validity of simulation results in comparison with results from actual flight tests, especially with regard to control engineering design studies.

In the framework of developmental work on the DO 31 project, the concept of the Dornier hybrid simulator was developed, by means of which it became possible to perform extensive tests and analyses in real time. In addition, this simulation technique enabled us to include real component parts in the simulation and to study and determine their dynamic behavior on the one hand and their effect on the total system on the other hand.

In a similar manner, studies on system analyses were conducted that were based on the experience gained with the DO 31 hybrid simulator. They covered the space travel projects Altitude Research Rocket (HFR) 621, "Astrid" and "Dachs" as well as Aeros A 2 and the aeronautical projects "Aerodyne," KAD and the rotating wing drone Kiebitz. The projects DO 31, HFR 621, "Kiebitz" and "Astrid" have already been tried out in flight.

The work on the projects "Dachs" and A 2 continues, but will come to an end in 1972. Work on project "Aerodyne" is complete to the point where flight tryouts can begin by the middle to the end of 1972.

Simulation Technology /32

The following tasks were in the foreground for complete or future projects at the firm of Dornier, employing hybrid simulation:

-- The determination of the dynamic behavior of the model in each case with different aerodynamic configurations, control elements and control effectiveness.

-- Basic system design or modification studies.

-- Determination of control engineering behavior and design studies for control and steering systems.

-- Determination of component specifications.

-- Conducting of hardware and component acceptance tests.

-- Steering platform design, pilot training.

-- Simulation accompanying flight testing in order to gain more detailed information regarding the to-be-expected dynamic behavior and to thereby reduce flight test risks.

Based on these specifications, the procedure is basically as follows for pure digital or analog, but also for hybrid simulation:

By means of long-term programs and simplified analog, digital /33
or hybrid simulation,those parameters are determined as far as that is possible to exert the greatest influence on the behavior of the to-be-tested flight gear. Parallel to these tests there are experimental tests on wind tunnel models, static models (moment of inertia, weight distribution, etc.), components and subsystems. An improved complete model is manufactured for simulation, using the thus-determined data.

Simulation must be organized so as to make use of real time simulation, that is, the inclusion of real component parts also, feasible.

Figs. 1, 2 and 3 show, in the form of characteristic examples, the organization of the hybrid program within one keying step (in the case of DO 31,"Kiebitz" and "Aerodyne"). It is essential for the avoidance of numerical instability that data input and output from and to analog computer peripheral equipment or actual parts takes place in such a manner that no phase errors occur. In addition, the selection of a keying period is important for a dynamically satisfactory simulation. Experience has shown that the keying period must amount to at least six times the highest eigenfrequency of the closed system.

By means of such a relatively complex, hybrid simulation, it is possible to perform, depending on the quality of the programmed models, very extensive experiments from a study of the practicability to the adjustment of hardware components and controls. However, the most sophisticated simulation is no substitute for flight testing.

Examples of Simulation /34

It is relatively simple to carry out simulations of missiles moving in space. The practically undisturbed flight dynamics are determined by clear physical laws. In this case, an extensive hybrid simulation is usually not necessary and is too expensive.

Within the last few years, the control system "Astrid" has been developed for a spin-stabilized payload of an altitude research rocket. The task set to controls consisted of aligning within 5 ft. the longitudinal axis of the warhead with a specified star. This system has been fired twice already. (The second FE on 11/16/1971).

In the case of "Astrid" a pure digital simulation in slow motion was first performed and, on the basis of this, the requirements for the components of the system were derived. The subsequent analog simulation was primarily for peripheral hardware testing.

On a three-axis air-bearing table in a total hardware simulation, the function and coordination of the components was tried out. On account of disturbances by gravity and atmosphere at the earth's surface, a proof of accuracy could only be obtained in peripheral hardware simulation.

Fig. 4 shows the variation in time of a control. The speed and position signals, modulated by a spin of 5.3 cps, decrease inside of 32.6 sec to the point of changeover into the next control position. The initial deviation amounted to approximately /35
35° and the initial speed to approximately 2°/sec. This simulation was performed by means of the real rate gyro.

In comparison, Fig. 5 shows the curve of the decline of the flight unit control electronics within the compass of a simulation with an acting time of 26 sec.

Fig. 6 shows a segment (target entry) of the signals sent by means of telemetry to the ground station during the firing of the FE 2. In spite of greater initial deviations and velocities, the acting time in this phase amounted to only 27 sec.

It is evident from these examples that the results from analog and peripheral hardware simulation are extensively transferable to a real flight. The reason is that:

1. The control in the aircraft was only set up in analog technology and the deviations between analog simulation and real flight were, therefore, confined in these components to the quantity customary between analogous building blocks of equal grade.

2. The flight engineering and dynamics of the whole system were to be confined to the equations of motion of an undisturbed system, free from outside forces, and able to be simulated accurately enough by means of an analog computer. In the case of "Astrid," the problem we were dealing with in the model consisted of describing the dynamics of a gyro free of forces and aligned by means of pulse-like actuating moments.

At the present time, we are proceeding in a similar manner in /36 projects "Dachs" with a triaxial stabilization for the warhead of an HFR and A 2. Functional and prototype tests with peripheral hardware have already been completed within the compass of a hybrid simulation (A 2).

As mentioned above, a hybrid simulation was carried out for the first time during the developmental work on project DO 31. After extensive presimulations, tests of partial and subsystems, more and more real parts were integrated into the pure software simulation: the entire hydraulics installation, the cockpit and the flight control assembly. This great effort was necessary for the simulation of the whole system to be as accurate as possible.

The outcome was that flight characteristics, which were the result of simulation research and that had been declared as unthinkable even by the test pilot, were verified in flight testing. The flight control assembly needed only slight correction, after having been adjusted within the orbit of the simulation. Fig. 7 shows a characteristic representation of the deviations between simulation and flight testing. It deals with a landing transition that was first performed in a flight test in accordance with testing directions. θ and lift engine-lever position $\hat{\sim}$ thrust as a function of ground distance were specified. The solid lines represent the result from "resimulation " and the dotted lines represent the results from flight testing. The deviations depend less on the accuracy of the model but can rather be traced back to unreproducible disturbances (gusts of wind, etc.) that accumulate in time. In addition, integration errors within the simulation cause deviations that become noticeable only after a longer period of time.

One of the most acute developments is the project "Kiebitz." /37 It deals with an unmanned rotor platform moored to a rope which is in the main planned for such tasks as reconnaissance, radio direction finding, surveying and communication. The system is designed as follows: the cell which contains a turbine, compressor and generator and stabilizing units and holds the useful load is held aloft by a two-blade, cold-gas reaction rotor. Fuel supply and data transmittal, as well as maintaining of altitude take place by way of the mooring line. The mobile ground station contains the energy supply and the guidance installation.

Constructing the mathematical model was in this case problematical because as a consequence of the large-scale and complicated calculations for rotor and mooring cable, a real-time simulation with an exact calculation of the dynamics of the system had become impossible. In consequence, the concept was to approximate the model as closely as possible for the entire dynamic performance in as wide a range as possible.

To this end, the reactions at the rotor were exhaustively studied in long-term simulations and simplified models were constructed and their behavior was correspondingly adapted and the range of validity was ascertained.

A similar procedure was adopted for the mooring cable which today, after several attempts with rods, compound cable or similar models, exists as a system of parts able to oscillate, the spring rates, damping elements, coefficients of expansion, etc. of which have been ascertained by means of separate tests.

The representation of time flow within one test period (Fig. 2), which in this case amounts to 25 sec, clearly shows the still-remaining difficulty of phase displacement. The time required for read-in of analog data until D/A conversion is 22 msec. The inadmissibly high phase displacement is limited to permissible size by means of extrapolation of the read-in analog data by T/2. The scanning frequency, therefore, is 40 cps, i.e., all time events up to approximately 4 cps can still be covered with sufficient accuracy. That is especially important for the dynamics of the rotor turning at approximately 6 cps. /38

By means of this simulation it was possible to determine the basic behavior of the aircraft or of subsystems, such as cable and rotor, and the design of the control and guidance equipment. The hardware controller was adjusted and tested in the simulation prior to installation in the aircraft. For the purpose of manual control, the pilot was included within the orbit of the simulation by means of a suitable visual representation and made acquainted with the dynamics of the aircraft.

Good coordination in the principal dynamic parameters was obtained in the flight tests that have been conducted for some time. Fig. 8 shows part of a flight at an altitude of 9 m with approximately 40 kp excess thrust and a mean wind velocity of v_{WX} = 2 m/sec. Step function-like signals on the cyclic blade pitch in the pitch axis of approximately 5° of servomotor deflection were used as disturbance variables.

Fig. 9 again shows a "resimulation" in which these cases of flights have been reproduced. /39

In the case of "Kiebitz," simulation and flight tests were also compared by means of such resimulation. By it, the following was established: in order to achieve stable flight performance, the controller had to be slightly readjusted. The necessary correction led to the conclusion that due to the so-called "control softness," additional dynamic delays between control element deflection and rotor blade pitch occur that are not simulated accurately enough in the simulation model.

Furthermore, the comparison shows that the temperature and vibration level of the aircraft causes additional disturbances in the sensors. As compared to simulation, this creates greater operational activity of the aircraft, which is especially evident in Fig. 8 in the integration of the acceleration signals.

Conclusion /40

The question regarding validity of a simulation model is extremely important for basic practicability; the answer, however, is connected with quite specific difficulties:

-- During tests certain areas of operation may not be crossed by the aircraft in flight on account of reasons of safety.

-- The unstable-by-nature conduct of the aircraft in the cases noted only permits operation with engaged controller.

-- Not all disturbance variables, such as all types of cable vibrations and completely accurate blowing of the wind in the case of "Kiebitz," can be covered.

For these reasons, it is first of all not a simple matter to unequivocally localize the respective cause for the occurrence of a different behavior of simulation and flight test. An extensive "real part" simulation has the great advantage in this case of eliminating to a large extent the question of a model for these subsystems.

For this reason, a comparison of simulation and flight testing in the cases noted was in essence conducted in the following manner:

-- A displacement of eigenfrequency of the closed system and the range of stabilization in flight testing permit a qualitative /41 evaluation of the differences between model and aircraft, in many cases even a statement regarding the kind and location of the cause.

-- By means of "resimulations" of flight tests the order of magnitude and the correctness of assumed disturbances and sensor errors can be checked.

-- By means of simulations parallel to flight tests, using simplified, special analog or digital models, characteristics of the system occurring only during flight testing can be studied at close range and clarified.

On the basis of many years of experience and the noted repeated possibilities of comparison between flight testing and real-time simulation, the question regarding validity can be answered as follows:

-- In our opinion, for design and systems research by means of real-time simulation, as a rule the balance is in favor due to the fact that the real aircraft performs better dynamically.

-- Real-time simulation models as a rule have only a more or less limited range of validity which, however, can be reliably pegged out by means of long-term simulations and basic research done on actual parts or by means of a rough calculation.

-- Within the scope of this range of validity, the dynamics /42 of the model are basically transferable to the aircraft.

-- In the case of pilot training at the simulator, especially for remote-control aircraft, control after a display is considerably more difficult than by viewing the actual aircraft.

-- For guidance of unmanned aircraft operating out of sight of the pilot a simulation of this type in comparison with actual flight is sufficiently accurate and the behavior is basically transferable to the actual flight test.

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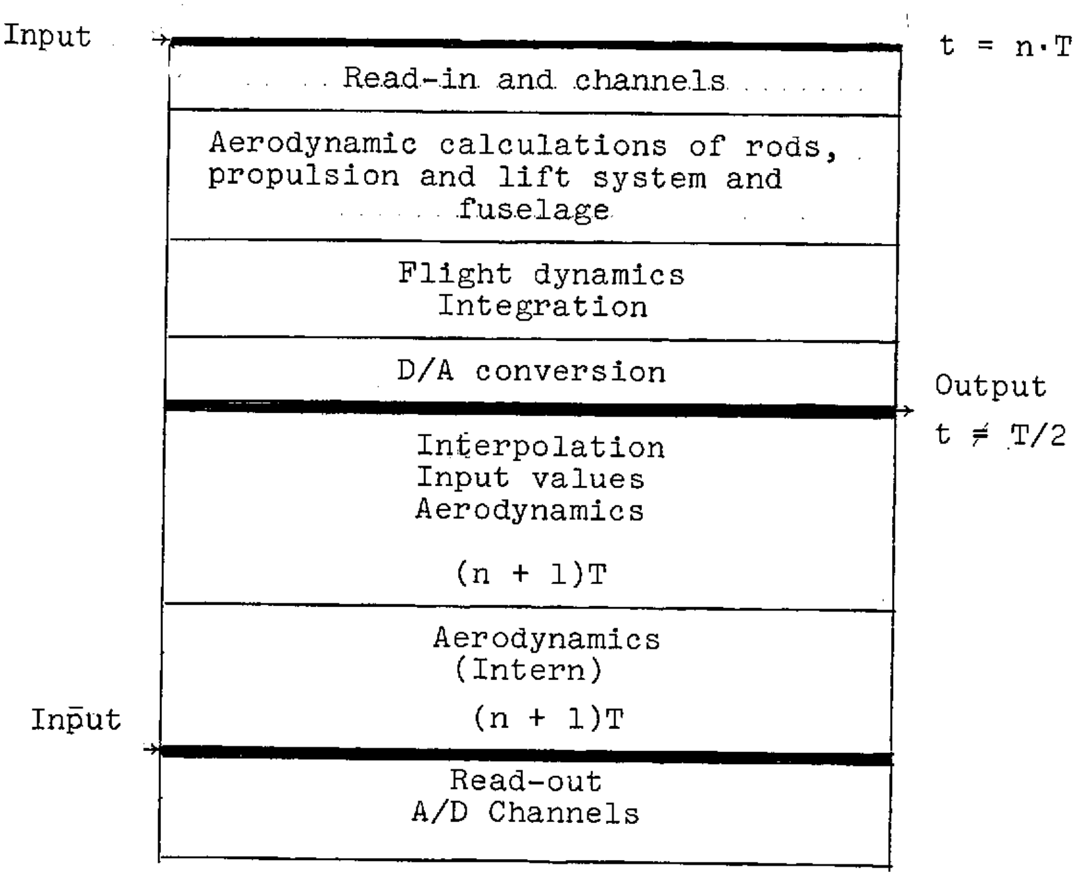

Fig. 1. Simulation DO 31 -- time sequence within one cycle.

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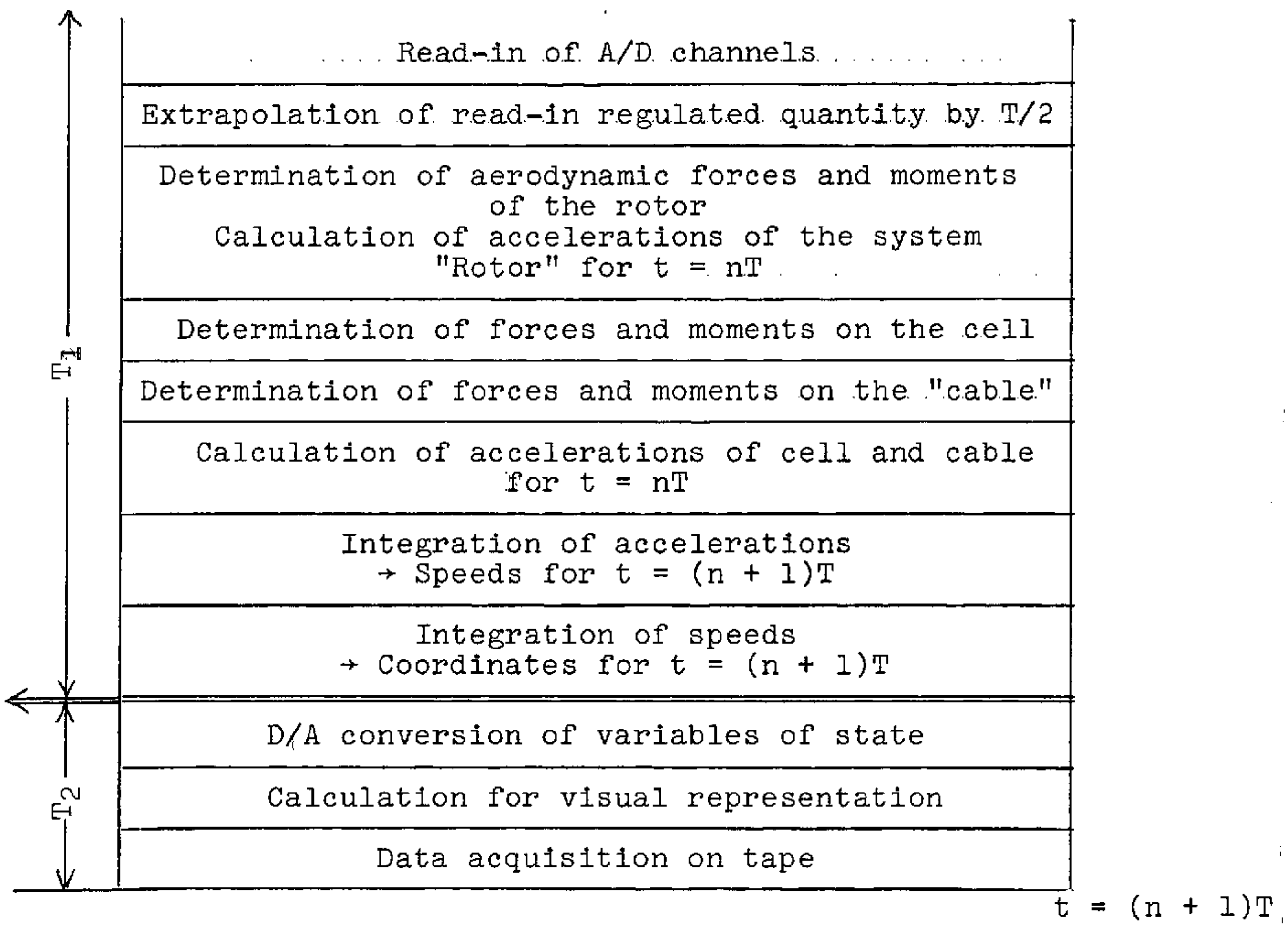

Fig. 2. Simulation "Kiebitz -- time sequence within one cycle.

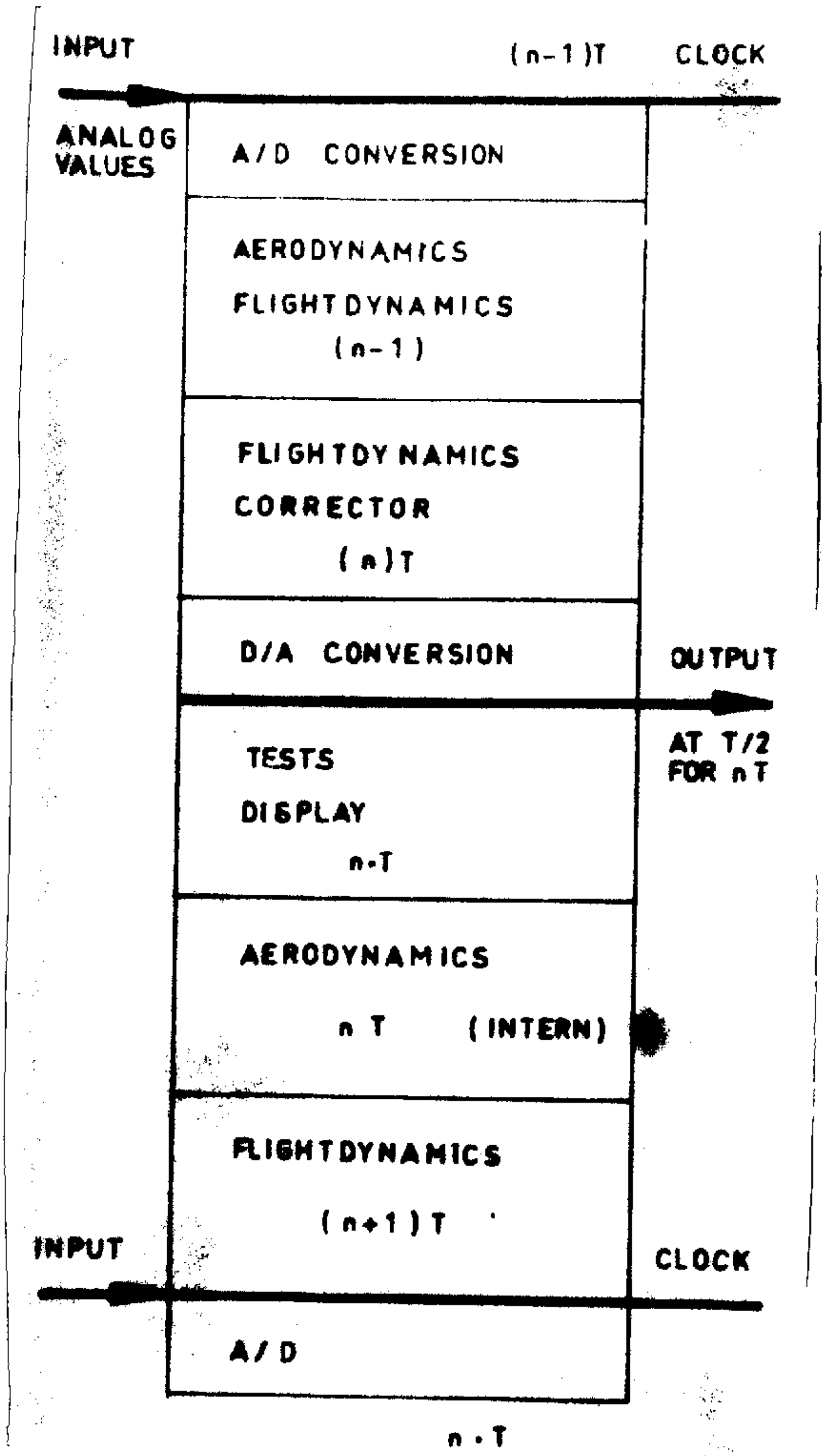

Fig. 3. Simulation "Aerodyne" -- time flow within one cycle.

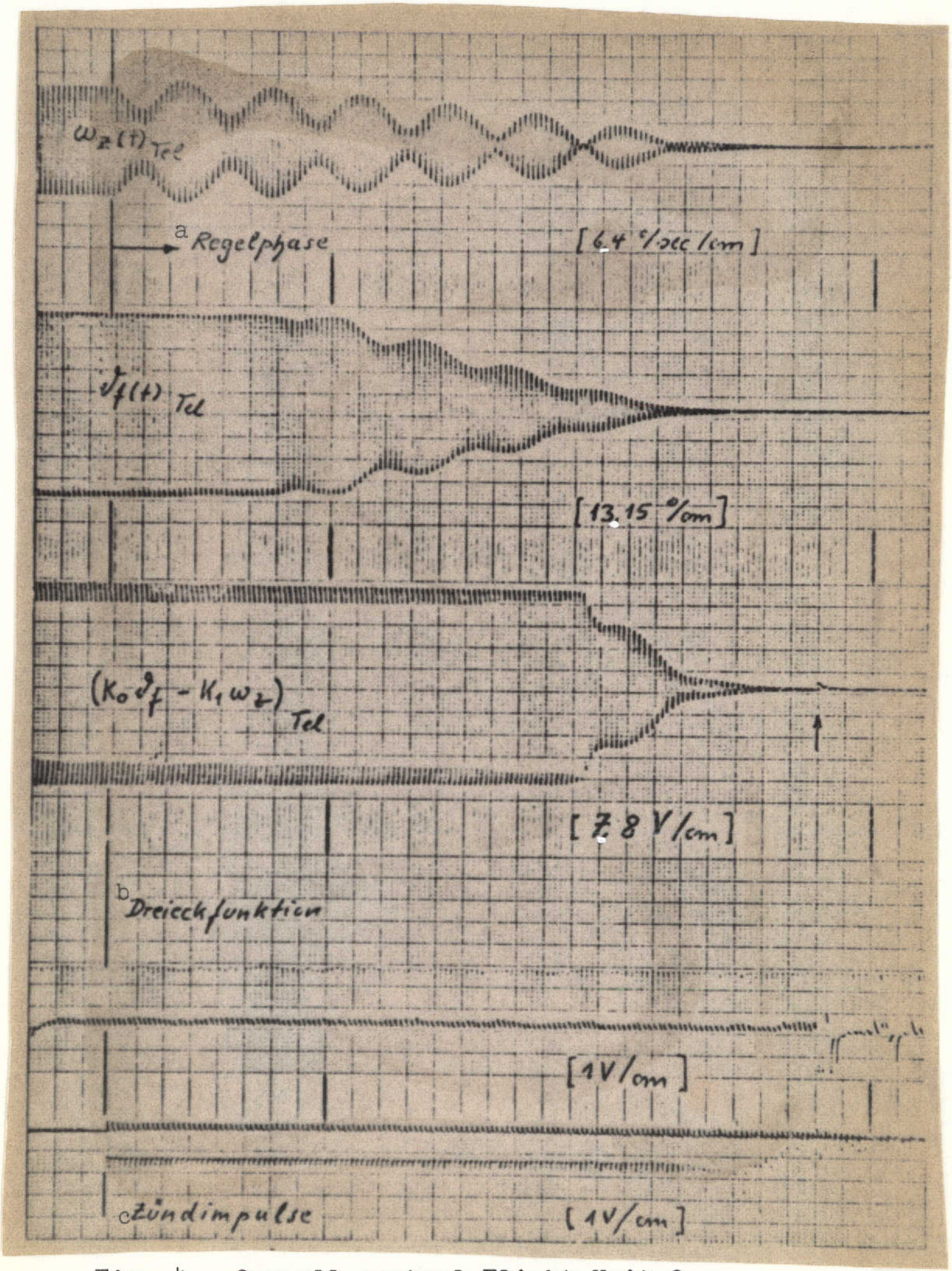

Fig. 4. Overall control Flight Unit 2,
Scale of time: 5 mm/sec
Spin frequency: 5.3 cps

Key: a. Control phase; b. Triangle function;
c. Ignition impulses

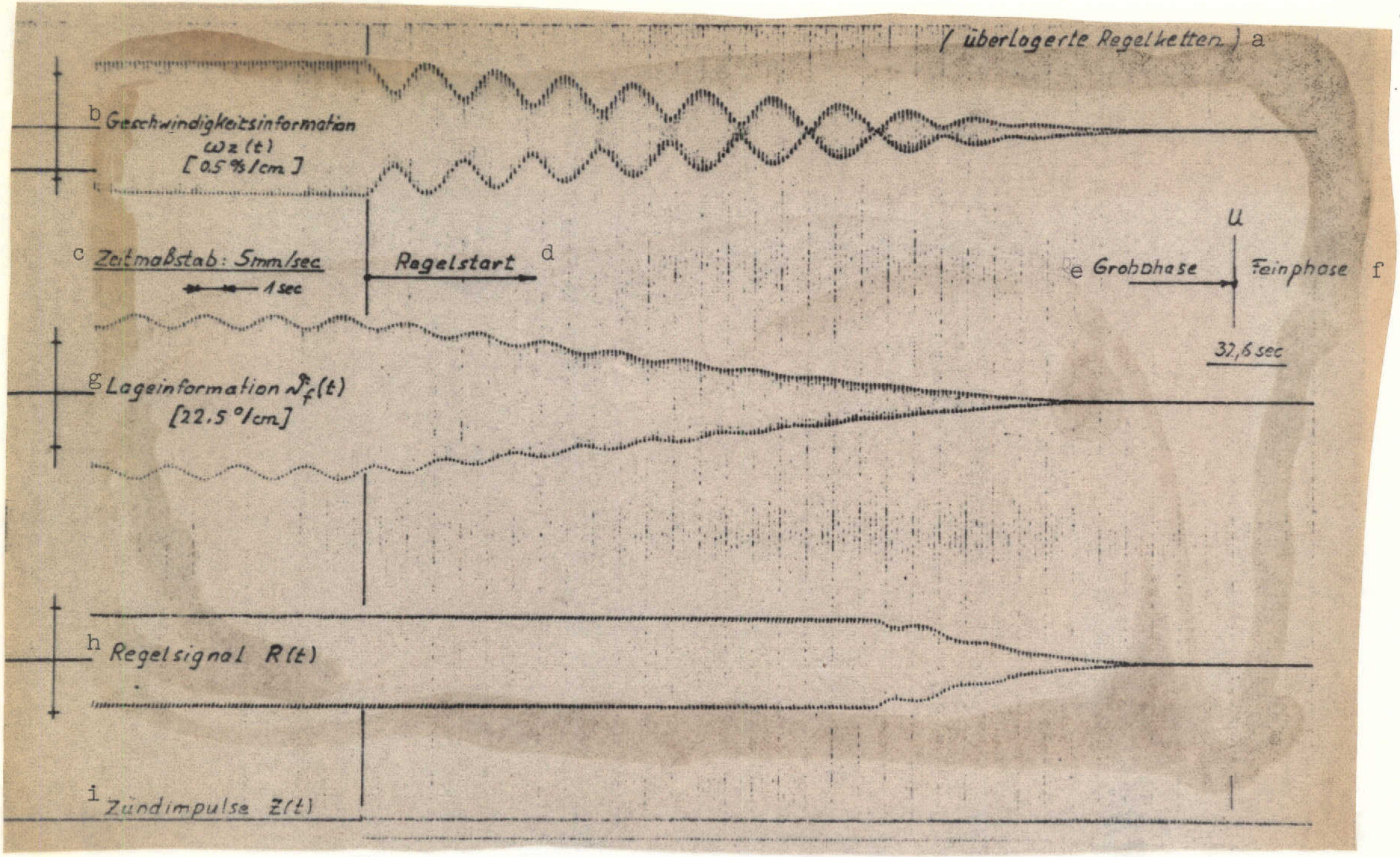

Fig. 5. Spin table test II, coarse phase.

Key: a. (Superimposed control chains)
b. Speed information ...
c. Scale of time ...
d. Start of control
e. Coarse phase
f. Fine phase
g. Position information ...
h. Control signal R(t)
i. Ignition impulses Z(t)

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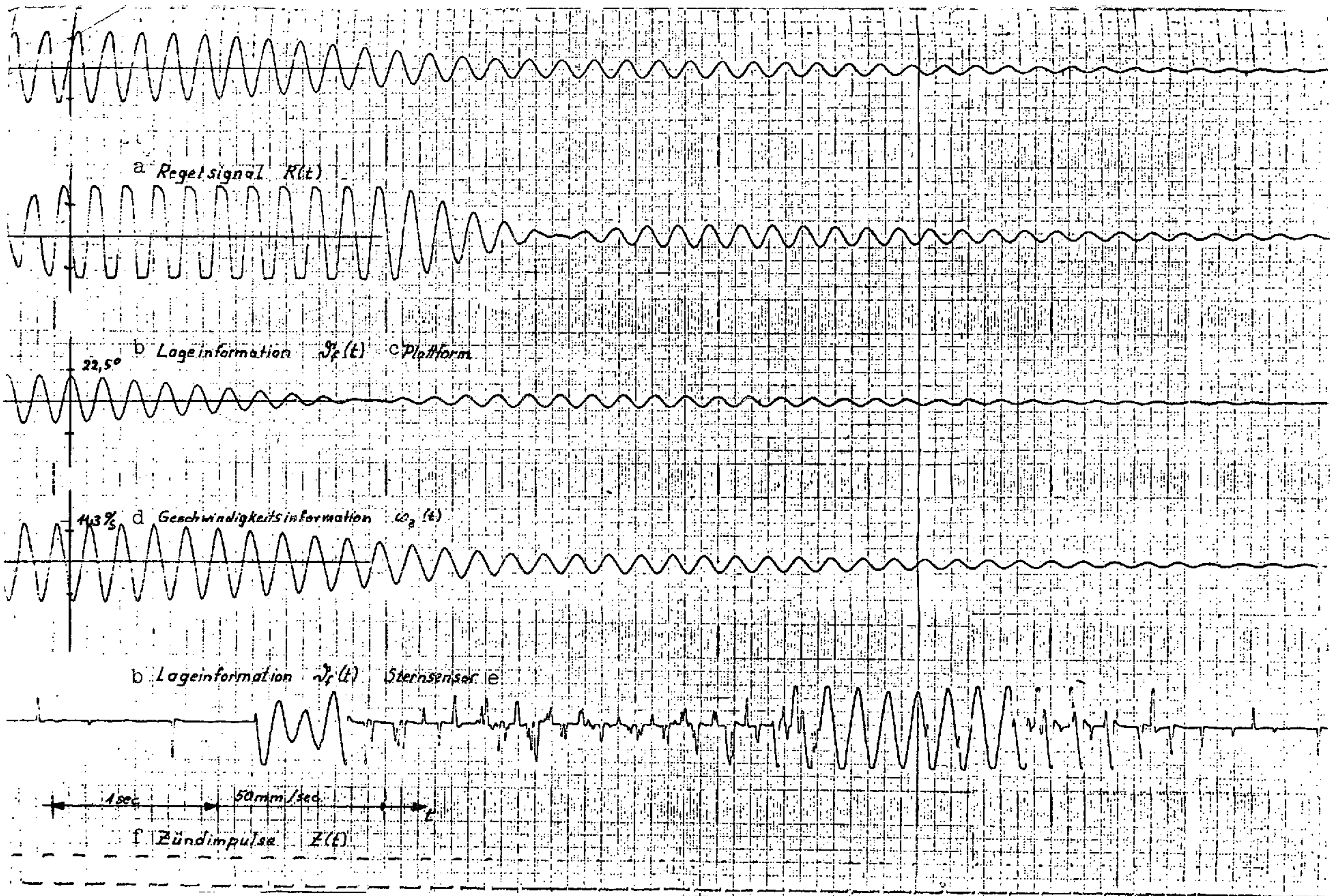

Fig. 6. Telemetry signals of the FE firing of 11/16/71 (target entry coarse control phase).

Key: a. Control signal r(t); b. Position information ...; c. Platform; d. Speed information ...; e. Star sensor; f. Ignition impulses Z(t)

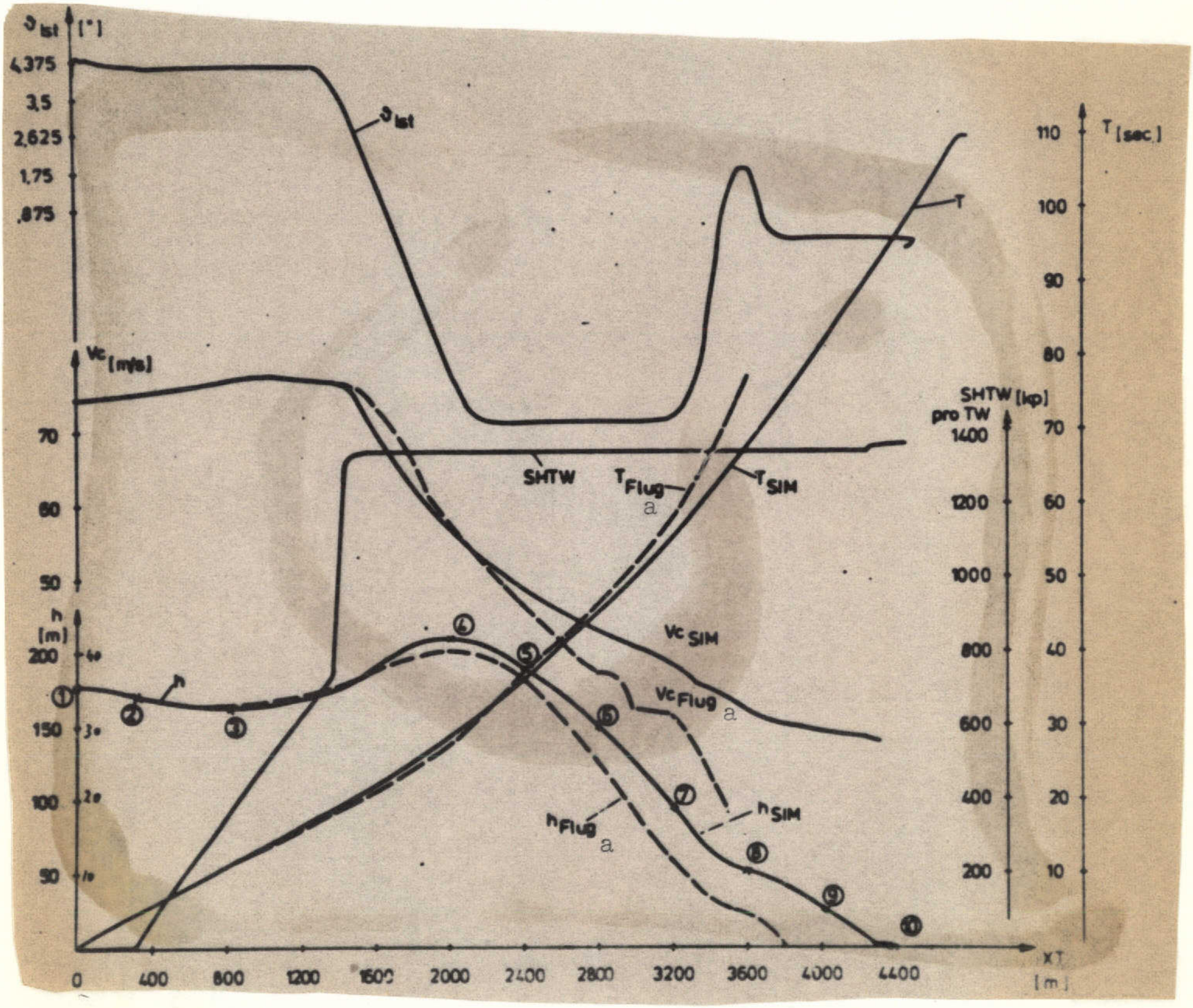

Fig. 7. Resimulation DO 31.

Key: a. Flight

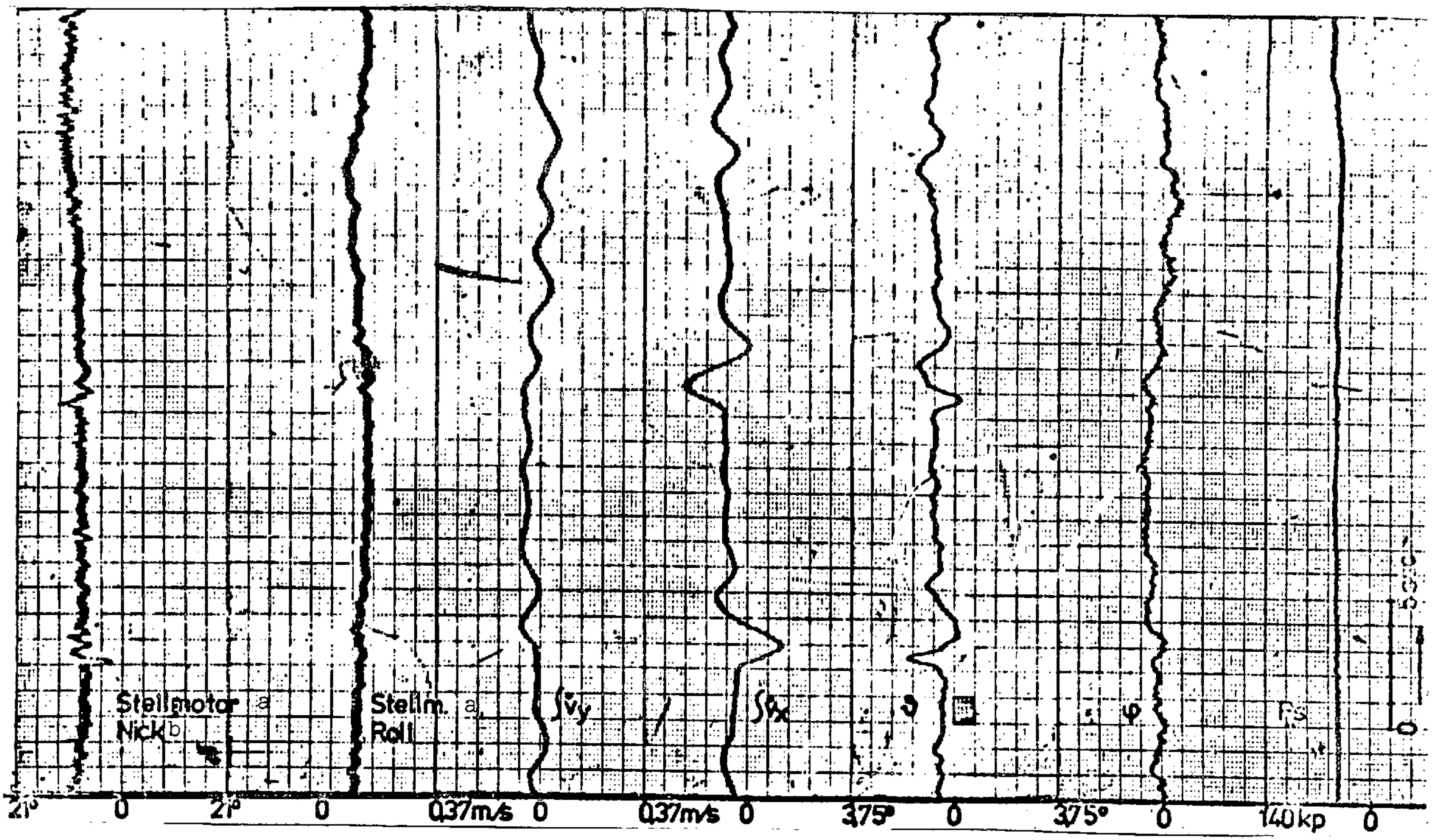

Fig. 8. Flight test "Kiebitz"
Key: a. Servomotor; b. Pitch

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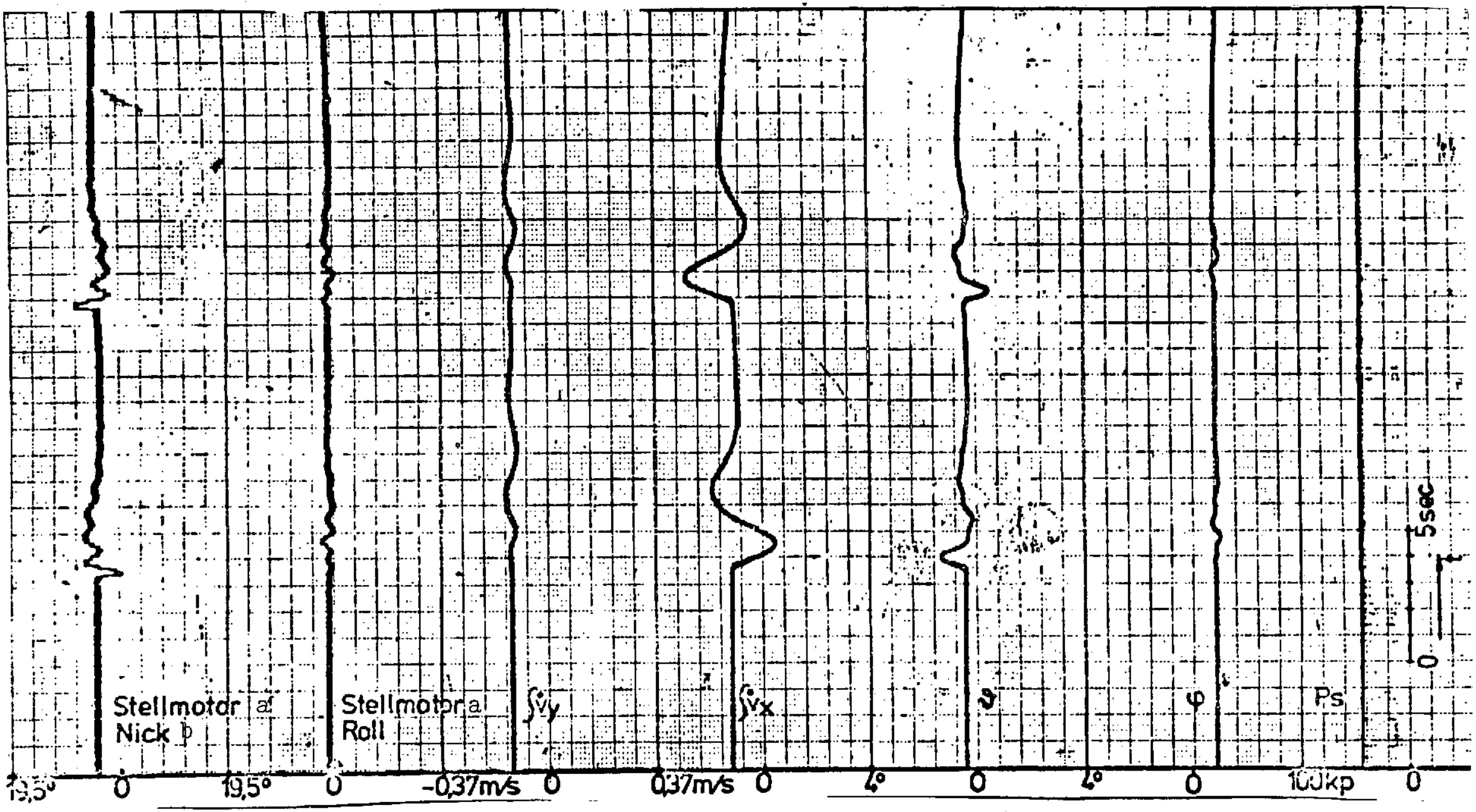

Fig. 9. Resimulation "Kiebitz."

Key: a. Servomotor
b. Pitch

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